Explanation of Plates.

Plate VII.

Fig. 1. *Holonema horrida* Cope ; lateral ventral plate ; two-thirds natural size.

Fig. 2. *Holonema rugosa* Claypole ; lateral ventral plate ; one-half natural size.

Fig. 3. *Holoptychius filosus* Cope ; scale ; two-thirds natural size.

Plate VIII.

Megalichthys macropomus Cope ; skull from above ; about three-fourths natural size ; from the collection of R. D. Lacoe.

Civil and Military Photogrammetry.

By R. Meade Bache.

(*Read before the American Philosophical Society, May 6, 1892.*)

Photogrammetry is recognized as a legitimate mode of surveying. It is, in fact, if practiced with due regard to the limitations involved through spherical aberration from object-glasses of too wide aperture, a mode of surveying of considerable accuracy, although not for a moment to be compared to other perfected modes of the present day. It can never rival these in their sphere, which is the sphere of extreme precision, but at the same time it must be admitted that, within its own, it is capable of doing good service.

The diagram on the blackboard has been made as simple as possible, to illustrate the mode of obtaining a single vertical and a single horizontal determination. It is evident, however, that the sectors of horizon and intervening landscape belonging to each picture, assumed to have been taken from the respective stations, *A* and *B*, might be filled with objects. Many of these, from the fact of their having been visible from both stations, would be determinable by this method of cartography.

AB is a base to serve for the determination of some of the details of a survey. The optical axis of the camera being set at each station respectively upon a prominent, distant object, say a lone tree, the angle at each station between the base and that object is taken.

The rays of light eA and cB, respectively, proceed from a steeple to the photographic points of view A and B. The intersection of these rays at S gives, according to the scale of the plotted base, the horizontal position by scale of the steeple with reference to those points of view.

In deference to a misunderstanding of which I heard lately, as to the relations of the horizons to each other, as represented in this diagram, I shall endeavor to preclude it now by calling attention to the fact that the horizons are here laid down as to direction, but in order to secure the utmost simplicity in the diagram, not as to their possibility of lateral extension. Objects, for instance, in the middle distance of the steeple, as seen in elevation on horizon A, from station A, would, at station B, fall to the left of the steeple, as seen in elevation on horizon B. Conversely, objects in the general direction, and in the background of the steeple, as seen in the elevation on horizon A, from station A, would fall to the right of the steeple, as seen in elevation on horizon B, from station B.

The chief method of photogrammetry in use at the present time is illustrated by this diagram, and is based on very simple principles. The angles and distances obtained in ordinary surveying are merely natural or artificial selections. They are merely arbitrary subdivisions of space, convenient selections from an infinite number of similar elements. But it is also true that, the relations of a few of those elements being judiciously selected and determined, all others secondarily deduced fall into harmony with them. The photographic camera, however, as compared with other surveying instruments, does not lend itself at first to selection, but giving all visible nature from various points of view, enables the employer of it finally to make his selection from the resulting pictures, as if from nature itself.

From all points of view, then, angles and distances exist in nature, and although they apparently change, as the observer changes place, the correspondences among them, as seen from all points of view, are perfect. Hence, if we delegate to the photographic camera the duty of making a permanent record of nature, as seen from two or more points of view, the intersection of the rays of light, reaching those points of view respectively from the same objects, as pictured in photographs properly placed, will, by their intersection on paper to become a map, give the positions of those objects relatively, as plotted, to the points of view and to one another.

Occupying with a photographic camera the points formed by the termini of a base line on the surface of the earth, having on its photographic plate imaginary vertical and horizontal lines, susceptible of being developed into real ones, the intersection of these lines corresponding with the centre of the prospective picture (the former enabling the operator to set the camera accurately to any horizontal direction, the latter giving, when the camera is leveled, the horizon for each picture), the camera is fixed in turn at the two stations upon some distant determinate object by its line of sight, its position being otherwise so adjusted that the objects to be determined in the landscape, within a given sector of the horizon, shall appear on the picture as taken from each of the two stations. The azimuth of the base line, and of the lines of sight from it, being determined by the theodolite, field transit, or compass, the survey for a particular sector of the horizon at the two stations lacks but one factor to make it complete, as soon as the pictures shall have been taken by the camera. The camera has given, by its occupation of the two stations at the ends of the base line of assumed length, only one portion of the data necessary to constituting a survey, namely, the angles subtended in nature by the various objects which come within the scope of both resulting pictures. A very simple addition, however, suffices to make the survey complete. To secure that, to introduce the element of scale, it is necessary to know the length of the base line. The scale to which the base line is plotted on paper becomes, then, through the acquisition of knowledge of the length of the base on the ground, the scale of the whole resultant map; which, it should be incidentally noted, must range by scale no further from each station than to a distance where rays of light to the two stations give good graphical intersection, the extent of the range by scale being conditioned upon the length of the rays by scale relatively to the length of the base line by scale.

Not only do rays proceeding from the same object, as introduced on two pictures properly placed, give by their intersection the horizontal position by scale of the object with reference to the base, but the angle subtended on any pictorial horizon by two objects, as seen from the properly plotted point of view of that horizon, represents on a map the actual visual angle as seen from that point of view in nature. In fact, the latter truth is that which is in nature the fundamental one in this connection. It is axiomatic that the visual angles in nature between all objects whatsoever, as projected on a given sector of the horizon, as seen by the eye of the observer, or that of the camera, from a given point of view, are the true angles between those objects, and that their sides, converged at the point of view, represent the true directions of the rays from those objects, corresponding with a base in nature with reference to which their angles are either directly or indirectly, in this case indirectly, known. Therefore it is because, in a *single* picture, the angles between different objects, in fact between all objects there, at the distance of the focal length of the camera, as seen in the picture from its plotted point of view, are the same as in nature from its point of view, that the intersection of rays from the same object, as seen on *different* pictures, placed in position corresponding with the way in which the landscape was photographed from nature, must represent by scale the horizontal position of the object as it stands in nature. That is to say, if what we see from one point of view in nature is true by angle, and also by angle true, although different, as seen from another point of view in nature, then the intersection of the individual rays, by means of which we have seen the objects in their angular positions with reference to each other, must represent their true horizontal positions with reference to the base which we have traversed between our respective points of view. And if this holds good with respect to nature, it must hold good with respect to corresponding pictures of nature, placed horizontally with relation to each other as nature had presented itself from those individual points of view from which the pictures were taken. The result, expressed as a surveyor would state the case, depends upon the fact that, if a point lies somewhere on a line, and also somewhere on a line intersecting the other, then the point will be at the intersection of the two lines. In this case the two lines are simply the visual rays, shown in the respective pictures, in the positions and with the angular effects as seen in nature, intersecting each other on their passage to the respective points of view.

In practice, a round of pictures, each taking in a certain sector of the horizon and intervening landscape, and slightly overlapping one another, is made to cover the tract of which it is contemplated to execute a survey, and the area comprised by them is pictorially duplicated from one or more stations. It is always desirable that the same objects shall be seen, if good intersection of rays can be secured from the different pictures, from three stations instead of two, because an error in one of the azimuths at the end of a single base, which of course gives only two lines for an intersection of rays, would vitiate a whole survey, whereas, with two bases, involving three points of view, and the intersection of three rays, accuracy throughout a survey receives a crucial test. The adoption of this plan, which is like that employed in ordinary triangulation, is also desirable on account of its securing accuracy of plotted results; because graphical differences in the positions, as given by the intersection of only two lines, are virtually eliminated by obtaining for intersections the mean positions as derived from three lines.

The survey, so far as the instrumental part of it is concerned, being complete, it only remains that the plotting of it shall be done. The base line being laid down to scale on paper, lines are drawn from its termini, at the angles with it represented by the azimuths of the lines of sight as determined there on the ground. On this representation on paper of the lines of sight, at the respective plotted stations, are placed, at right angles, printed on thin paper, the photographs taken at the two stations, in such manner that the individual plotted line of sight shall point on the photograph upon the representation of the object upon which the real line of sight was directed in nature, after that representation shall have been vertically projected on the horizon line of the photograph, and that the horizon line of the photograph shall be distant from the individual plotted station by the focal length of the particular camera that was used in taking the pictures. The eye then, placed in position over a plotted station, and looking at a photograph corresponding to the view taken from that station, sees, as already demonstrated, that view under precisely the same angular effect as the view is presented by nature on the ground. Consequently, as angles formed by rays of light with the base line are given truly in nature, are also given truly by the camera, and are now given truly as plotted on paper to become a map, the intersection on that paper of these rays, as proceeding from the pictorial representation of the objects from which they are derived in nature, after their pictorial source has been vertically projected on the horizon line of the photographs, will be the positions of the objects on the map, with due relation by scale and angles to the stations of the base line and to one another. The contemplated map will, in a word, be susceptible of being drawn throughout to scale. It is clear that a great number of objects may be thus plotted from two stations representing the ends of a base line, and that if we know the length and azimuth of a base line, and the azimuths of the lines of sight from its termini, the elements of scale and orientation will inhere in all the resulting work that goes to form a map. Used for the function described, the photographic camera is therefore very aptly called the camera-theodolite.

Adopting the same diagram to illustrate the mode of determining height by the camera-theodolite, we see the steeple, as observed upon from the point of view A, having the ray eA coming from the photographic position of the steeple as projected on the horizon line of the photograph taken from A. Draw from the point e the height of the steeple, as derived from the photograph taken from A, perpendicularly to the ray eA, and draw also the hypothenuse Ad. Any one intuitively perceives that the pictorial height of the steeple being ed at e, at the end of the focal length of the camera, its height at S, the horizontal position by scale of the steeple, must be Sf, and that that by scale is the true height. The length of the line Sf may therefore be obtained numerically by applying to it the scale of the base, which may be the scale of a whole map. With a greater degree of precision the same result may be reached by computation, because $Sf = AS\frac{ed}{Ae}$; $\frac{ed}{Ae}$ being the tangent of the vertical angle $d\ A\ e$, and AS the distance from the point of view A to the steeple S.

Of course the height of any natural as well as of any artificial object above the plane of the horizon may be ascertained by similar means. A steeple was chosen to illustrate both horizontal and vertical methods of determination, because it affords points that are so conspicuous as compared with those of many other objects that offer themselves to the sight in most surveys.

Surveys from this kind of photogrammetry may be plotted to any scale, within reasonable limits of size, by adopting for the base line of the survey the scale desired. In all cases, however, the photographic pictures must, in order to enable them to present correct angles for the map, be placed in the manner already prescribed, on the respective horizons as plotted on the paper to become a map.

Balloon photogrammetry has been practiced to some extent ever since the invention of the photographic dry plate. This method, however, has belonged rather to the sphere of reconnoissance than to that of surveying. When some prominent objects appear on the landscape, whose geographical relations to one another are known, the balloon photographic product may be of considerable value, if too large a circle has not been included by the camera; and this method indicated, if the desirable conditions are strictly fulfilled, may be utilized to advantage if the resulting map is not required to be of rigid accuracy. When, however, such objects are very remote from one another, even when their geographical positions are known, the spherical aberration resulting from employing a large aperture of object-glass makes a product which cannot be regarded as of high value, one which cannot properly be dignified with the name of survey in the restricted sense of the term, and to which we should prefer to apply the name of reconnoissance. Without adjusted height for the camera, without near objects of known geographical relations to one another, to obtain orientation for the results, without precise regulation of the angular aperture of the object-glass of the camera, nothing can be produced by balloon photographic process that, in the restricted sense noted, merits the name of survey.

It is on account of my perception of this low estate of balloon photogrammetry that my attention is especially drawn to devising a method of applying the art upon true principles. By my method the balloon must be captive, not free, and being captive it may be made quite small, easily managed, and inexpensive, thus rendering its employment practicable for ordinary use, especially as, according to the plan sometimes adopted in the case of the military captive balloon (to the consideration of which we shall presently come), the gas requisite for inflating the balloon can readily be carried under high pressure in metallic cylinders.

The traverse line of land surveying is merely a zigzag course, consisting of stations, the angle between each successive three of which, and distance between each successive two, is measured. From these stations details of the terrene are generally procured.

To enable a traverse line to form a portion of a general survey, there must be means adopted to place at least its initial and terminal points in relation to that survey, whereby all intermediate points fall into due relation with it.

This premised, I will now describe how my plan for introducing precision into balloon photogrammetry could be applied in various useful ways for delineations of portions of the earth's surface.

The appliances needed for carrying out the plan are a small spherical balloon capable of supporting a light photographic apparatus, swung in gimbals, and protected from injury in descent by a thin encircling cylinder of metal or of wood. A zone of cord would pass horizontally around the balloon, to which would be attached four equidistant guys of the size of codfish lines. A broad colored stripe would pass vertically around the balloon. From below the balloon would depend reophores enclosed in a graduated cord, the graduation serving the purpose of adjusting the balloon to any given height above the earth. The reophores would be electro-magnetically connected with the shutter of the camera, actuated from the ground by a small, but strong, galvanic battery.

The balloon, being inflated, would be compelled, by means of the four equatorially fastened guys, to assume a position regulated as to height by the graduated cord. This height will have been previously determined upon with reference to the scale of the map that may be desired, the focus of the camera having also been adjusted with reference to the contemplated height of the instrument above the earth. The position of the balloon would be over the middle of a given link of a traverse line, the orientation of the camera being secured by causing the vertical stripe on the balloon to range along the given link of the traverse line. Two disks, made of hoops covered with white cotton cloth, one of which should be larger than the other, would give on the photograph, points representing the termini of the link corresponding to those on the ground, and the direction in which the link, as a portion of the traverse line, is lying.

A very low grade of accuracy could be obtained by the balloon photogrammetrical process by the method of omitting all angular and linear measurements on the ground, and letting the balloon camera, placed in a generalized position with reference to the parts of a traverse line, accomplish the whole work of determining the angles and directions of the parts of the line successively submitted to its operation, as well as of delineating what it must perforce include by the photographic process in the representation of the details of the subjacent terrene. In this method the end link of a given section of the line would have to be duplicated in the advancing survey of the line, so that the relations with one another of all parts of the line should be maintained. If, additionally, the azimuth of one of the links of the line were obtained, it would communicate azimuth to all the other links. But this method can, at best, be recommended for nothing beyond the requirements of reconnoissance.

The photographing of a link of a traverse line in the precise manner first described involves, of course, the necessity that the balloon and each of the two stations representing the link over the middle of which it is floating, should be intervisible. A similar condition, as between the two stations as viewed on the ground, is indispensable. It is evident, however, that if there are trees or other obstructions on the ground, the stations might be intervisible below, and yet that each might not be intervisible with the balloon. Consequently, as not only these conditions but the condition of ample space for the management of the guys must be fulfilled, precise operations with the balloon imply the existence of open ground, or ground substantially free from obstructions to sight.

In proportion as the balloon is allowed to attain a greater and greater height, so as to include more and more of the earth's surface, the scale of the resultant map would become smaller and smaller, and the apparatus more and more unmanageable, because at a great height the guys cannot be maintained at the angles requisite to control its exact position. Therefore, it will in practice probably be found that heights of from three hundred and fifty to five hundred feet will be those most convenient for surveying by this method.

One gain made by elevation is more than counterbalanced by the loss of the clearness of delineation that belongs to a large scale. It is evident that, at moderate heights, the photographic projection of an abrupt rise of ground or other object, as, for instance, a house, on the plane of the photograph is at a greater distance by scale from the vertical passing through the balloon than it should be as related to nature, but that, as the height of the balloon above the earth increases, this error proportionately decreases. Therefore, for the moderate elevation that must be adopted for the balloon in order to manage it, we must, with broken surface, accept greater error in delineation than would attach to the same surface if greater elevation of the balloon were permissible. But we should be reconciled to this fact from the consideration that, even were it possible to manage the balloon at the height which would virtually eliminate the error of projection mentioned, the scale of the resulting map would be so small as to approach in character the results of a reconnoissance. Another circumstance should reconcile us to the insuperable fact mentioned, and that is that there are thousands of square miles in our country where, from the very fact that the surface is essentially level, the optical difficulty attaching to moderate elevation for the balloon would not exist.

Such a survey, by balloon photogrammetry, as that described could be very easily plotted by final process of photographic printing. In consequence of the fact that the balloon would be kept at a fixed height throughout a given survey, the scale of the links of the traverse line would be established through the photographic presentment of the length of those links. The scale of those links may also be fixed by the measurement of them on the ground. So the photographic scale and the other scale may be made the same, and therefore they would be made the same. The traverse line having finally been laid down on helios paper, before the paper is sensitized, the paper would then be sensitized, and the photographic plates representing the links of the traverse line would be simultaneously adjusted upon it along the traverse line as plotted, one scale, as derived from adjusting the balloon at a certain height, and the other scale, virtually the same, as derived from linear measurement along the ground, being made to accommodate themselves graphically to each other, thus eliminating error in the resultant map. This resultant map, if the picture of a plane surface, would have but one defect, that of exhibiting minute triangles of blank space where the photographic plates, cut off so as to fit along the links of the plotted traverse line, would necessarily not fill out entirely the delineation of the ground at those points, although otherwise perfecting it elsewhere, from the fact that they would form with one another a continuous series.

The captive balloon, if used only on days fit for ordinary field work, would occupy a position of almost stable equilibrium, if its power of flotation were sufficient, not only to support the photographic apparatus, but to strain upward upon the controlling guys, because the attachment of the guys would be made to the equator of the balloon, and the weight of the dependent apparatus would be close to its periphery, and therefore to the centre of the spherical figure of the balloon. In addition, for the purpose of increasing the stability of the balloon at the critical moment of taking a photograph, the operator would steady it with a gentle draught upon the dependent cord containing the reophores, at the precise point of time when he makes the electrical contact with the shutter of the camera.

I here conclude the description of that one of my proposed additions to the art of photogrammetry which relates to precision of results obtainable from it for a continuous line of survey, and invite your attention for a moment to a method I suggest of using a similar captive balloon in a manner which would be useful in military operations. It need hardly be said that, whether captive or not, balloons have heretofore been used at great disadvantage in military operations, unless we except the use made of them for escape, with indirect reference to those operations during the recent siege of Paris. If the free aëronautic balloon passes over the enemy at such a distance as to make useful what can be observed from it, the glimpse is but transient, while its nearness and immense volume place it in great danger. If, on the other hand, a captive aëronautic balloon be used for military observation, it must ascend far from the enemy, to a height which measurably neutralizes the accuracy of the information sought.

The use for military purposes of a modification of the small spherical captive balloon which I have described would be conditioned solely upon the circumstance that the wind should be blowing towards the enemy's lines. The only change in it from the one described, that would be entailed by its new purpose, would be that it should be mounted with a simple network similar to that which is used on the kite, and to which the string for flying it, fastened similarly to the way in which it is fixed on the kite, should be attached. This string, with which the balloon would be flown like a tailless kite, would contain ordinary filigree reophores, through whose instrumentality the photographic shutter of the camera would be controlled by the operator. Lying several hundred yards away, or even a mile or two, if desirable, outside of an enemy's lines of circumvallation, or line of battle, with the wind blowing in his direction, the balloon could be sent up with ballast proportioned to the general elevation intended for its soaring over his position. I have said "general elevation," because change of volume in the balloon, in accordance with the change of temperature, or increased weight on it, from an accession of moisture, preclude the possibility of calculating upon obtaining precise predetermined elevation for the balloon. The weight of the string for the length to be paid out to the contemplated distance would of course enter into the amount of ballast needed to secure an approximately special elevation at a special distance. The distance to the enemy's position being known, and the vertical angle being taken to the balloon from its point of departure, when it is approximately delivered at its destination, the exact remaining length of string, with allowance for sagging, necessary to pay out so as to cause the balloon fairly to dominate the enemy's military works or line of battle, would at once be known by a simple computation, or could be taken from a table of angles and distances. This operation being completely performed at several points along the opposing military lines, a series of pictures, at varying distances from front to rear, and from right to left of the enemy's position could be secured by means of the electro-magnetic attachment to the shutters of the photographic cameras, each individual one of which could take a number of pictures without replenishment of plates. It is evident that such a use of the balloon and the photographic camera would have proved greatly advantageous to either side in such modern sieges as those of Sebastopol, Richmond, and Paris.

On the Skull of the Dinosaurian Lælaps incrassatus Cope.

By E. D. Cope.

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The characters of the skull in the carnivorous Dinosauria are only partially known, so the present opportunity is improved to add to our knowledge a considerable number of points, if not to exhaust the subject. I have temporarily in my possession two incomplete crania of the *Lælaps incrassatus*, from the Laramie formation of the Red Deer river, in the Dominion of Canada, which have been submitted to me by the Geological